

**SPEED ESTIMATION TECHNIQUES FOR
INDUCTION MOTOR USING DIGITAL SIGNAL
PROCESSING**

SOLLY ARYZA

**MASTER OF ELECTRICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG**

**SPEED ESTIMATION TECHNIQUES FOR
INDUCTION MOTOR USING DIGITAL SIGNAL
PROCESSING**

SOLLY ARYZA

**Thesis submitted in fulfillment of the requirements
For the award of the degree of
Master of Engineering (Electrical)**

**Faculty Kejuruteraan Electrical Engineering
UNIVERSITI MALAYSIA PAHANG**

2011

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion this thesis is satisfactory in terms of scope and quality for the award of the degree of Master of Engineering (Electrical).

Signature :
Name of Supervisor : Ir. Zulkeflee Bin Khalidin
Position : Dean
Faculty of Electrical Engineering
Universiti Malaysia Pahang
Date : 23 November, 2011

Signature :
Name of Co- supervisor :.Dr. Ahmed N Abdalla
Position : Association Professor
Faculty of Electrical Engineering
Universiti Malaysia Pahang
Date : 23 November, 2011

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :
Name : SOLLY ARYZA
ID Number : MEE 10003
Date : 23 November, 2011

TABLE OF CONTENTS

SUPERVISOR'S DECLARATION	
STUDENT'S DECLARATION	
DEDICATION	
ACKNOWLEDGEMENTS	
ABSTRACT	
ABSTRAK	
TABLE OF CONTENTS	
LIST OF TABLES	
LIST OF FIGURES	
LIST OF SYMBOLS AND ABBREVIATION	

CHAPTER 1 INTRODUCTION

1.1	Background of Research	1
1.2	State Estimation Sensor less Electric Drives	2
1.2.1	Flux Estimation for Field Orientation	4
1.2.2	Flux Observers From State Space Control Theory	4
1.3	Problem Statements	5
1.4	Research Objectives	5
1.5	Scope of Thesis Work	6
1.6	Contribution	6
1.7	Thesis Outline	6

CHAPTER 2 LITERATURE REVIEW

2.1	Induction Motor	8
2.2.1	Stator	10
2.2.2	Squirrel Cage Rotor	11
2.2	Frequency Controller	11
2.3	Space Vector Pwm Control	12
2.4	Adaptive Pid Regulator	16
2.5	Artificial Neural Network	18
2.6	Digital Signal Processing Implementation Of Speed Sensorless FOC	23
2.6.1	Hardware Implementation of FOC	24
2.6.2	DSP Software Implementation of FOC	25
2.7	Summary	25

CHAPTER 3 METHODOLOGY

3.1	Introduction	26
3.2	Speed Estimation Using Direct Torque Control	26
3.3	Speed Estimation Using Vector Control	27
3.4	Speed Estimation Using State Equations	28
3.5	Speed Estimation Using Rotor Slot/ Bar Harmonics	31
3.5.1	Tapped Windings	32
3.5.2	Stator Current	33
3.5.3	High frequency Injection	33
3.6	Strategy Controller Motor	35
3.6.1	Scalar Control	38
3.6.2	Vector Control	41

3.6.3	Direct Torque Control	43
3.6.4	Feedback Linearized Control	44
3.7	Intelligent Artificial Controller	47
3.8	Proposed Adaptive System Using Neural Networks	54
3.9	System Configuration	55
3.9.1	System Overview	55
3.9.2	Motor Controller	56
3.9.3	Synchronous Angle Calculator	57
3.9.4	Current Control of Voltage Converter	57
3.9.5	Inverter Controller	57
3.9.6	Speed Estimator	58
3.10	Voltage Model Compensated by Rotor FOC Model	59

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Introduction	61
4.2	Simulation Result	61
4.3	Comparison of Induction Motor Operation	61
4.4	Hardware Experimental Setup	68
4.5	Performance	72
4.6	Result	73
4.7	Conclusion	76

CHAPTER 5 CONCLUSION AND FUTURE WORK

5.1	Conclusion	77
5.2	Suggestion Future Work	77

REFERENCE

APPENDIX

LIST OF TABLES

Table No.	Title	Page
3.1	Parameter of three phase induction motor	59
4.1	Comparison Operation of Induction Motor Used ANN and Modified Voltage Model Flux	66

LIST OF FIGURES

Figure No.	Title	Page
1.1	Sensorless Speed Estimation Methods	4
2.1	Cross Section of An Induction machines	10
2.2	Resultant Vector Representation of The Three Phase Currents	11
2.3	Conducting Rotor Bars Without The Rotor	12
2.4	Open loop Voltage and Frequency Controller	14
2.5	Close Loop Speed Control With Volts/Hertz Control and slip regulation	16
2.6	Current / Slip scalar Control scheme	19
2.7	Direct Torque Controlled Induction Motor Drive	20
2.8	Feed Back Linearization Control	20
2.9	Reference Frames and Representation of Stator current and Rotor Flux as Space Vectors	21
2.10	Three Phase Voltages Sources Inverter	24
2.11	Configuration of Space Vector PWM	26
2.12 a	Example of Space Vector PWM Pattern Reference Voltage and Projections	28
2.12 b	Example of Space Vector PWM Pattern in Sector 3	28
2.13	Adaptive PID Control	30
2.14	Schemes of ANN for Controller	33
2.15	Experimental Set Up for Sensorless Control System	38
3.1	Speed Observer Using State Equations	43
3.2 a	Rotor Flux Orientation Control Stator Reference Frame	49
3.2 b	Rotor Flux Orientation Control In Estimated Rotor Flux Reference Frame	49

3.3	Typical Induction Motor Drive	55
3.4	Detailed Laboratory Set Up	56
3.5	Implementation Procedure of The Control and Estimation	57
3.6	Block Diagram of MRAS Speed Observer	57
3.7	Proposed System Configuration	60
3.8	Proposed Modified Voltage Model	64
4.1	Experiment Set Up Induction Motor Based On DSP	66
4.2	Block Diagram TMS320F28335	67
4.3	Induction Motor 3 phase	68
4.4	Experimental Set Up	68
4.5	Simulation Speed for High Voltage	70
4.6	Simulation for 35 V Constant Rotating Simulations	70
4.7	Simulation for Torque of speed Estimations IM with Percentage Full Load	71
4.8	Modeling Speed Estimation Controlling Induction Motor	73
4.9	Stator Controlling Circuit	73
4.10	Estimators Adaptive in Controlling	74
4.11	Stator Current	74
4.12	Speed Result	75
4.19	Torque Result	75

LIST OF SYMBOL AND ABBREVIATION

PWM	Pulse Width Modulation
AC	Alternating current
HP	HP Horse Power
ANN	Artificial Neural Network
S	Slip
R1	Stator resistance in ohms
R2	Rotor resistance referred to stator in ohms
R0	Equivalent resistance corresponding to the iron losses in ohms
L1	Leakage inductance of Stator in henry
L2	Leakage inductance of Rotor referred to stator in henry
L0	Magnetizing inductance of the stator in henry
X1	Leakage reactance of Stator in ohms
X2	Leakage reactance of Rotor referred to stator in ohms
X0	Magnetizing reactance of the stator in ohms
V_i	Input voltage in volts
V₀	Output voltage in volts
V₁	Voltage across the variable rotor resistance in volts
V_f	Output voltage due to forward field in volts
V_b	Output voltage due to backward field in volts
V₀	Output voltage
I	Current flowing through the stator in Amps
I₁	Iron-loss and magnetizing component of the no-load current in Amps due to forward field
I₂	Rotor current referred to the stator in Amps due to forward field
I₃	Iron-loss and magnetizing component of the no-load current in Amps due to backward field

I_4	Rotor current referred to the stator in Amps due to backward field
P_{gf}	Airgap power developed by the motor due to forward field
P_{gb}	Airgap power developed by the motor due to backward field
T	Torque developed by the motor in Nm
T_L	Load Torque in Nm
N_s	Synchronous speed in rps
J	Moment of inertia in Kgm²
B	Viscous friction in Nms
P	Number of Poles
ω	Angular speed in rad/sec
θ	Angular displacement in radians
Y	Output vector of the hidden layer
O	Output vector of the output layer
V_{ji}	weight matrix
W_{kj}	weight matrix
B_1	Bias vector
B_2	Bias vector
T_r	Input
L_r	Output
R_r	Secondary time constant
L_m	Secondary inductance per phase
R_s	Secondary resistance per phase
L_s	Magnetizing inductance per phase
v	Primary winding resistance per phase

ABSTRACT

Speed estimation is one of the methods of speed sensor-less control for three phase induction motors. With the advancement of the power electronics switching devices and digital technologies, the developments of speed estimation methods have been intensively implemented from many researchers. Thus, this field of research has become more interested to investigate. Speed sensor-less control techniques can make the hardware simple and improve the reliability of the motor without the introducing the feedback sensor and it becomes more important in the modern AC servo drive. It is one of the attracting research directions in the high-precision servo control field because of its robust characteristics, simple realization and excellent dynamic response. Several common rotor speed estimation was introduced in the thesis. The model must accurately represent both the electrical and electromagnetic interactions within the machine and associated mechanical systems. In this Thesis, the neural networks controller for speed estimation has been developed approach to induction motor that has been implemented in digital signal processing controller (DSP) and gave the control signal to IGBT for run three phase inductions motor. Analysis of speed estimation nonlinear characteristics is carried out and makes a comparison with traditional linear method speed sensor less method. First, the simulation of the proposed control system is performed by using the MATLAB software and then the real time implementation is performed by using the MATLAB and the hardware. According to the mathematical model of the induction motor, the simulation of model and hardware implementation of speed sensor-less induction motor had been successfully implemented. The design and implementation of the speed estimation system for three-phase induction motor and the experimental research is presented in this Thesis. Finally, this Thesis shows the implementation of the speed estimation using DSP controller and the design of hardware and software for speed sensorless of induction motor. The experiment is completed at different speed and experiment results show that artificial neural network controller obtained a good response when compared to conventional methods.

ABSTRAK

Anggaran kelajuan adalah salah satu kaedah kawalan kelajuan sensor-kurang selama tiga fasa motor aruhan. Dengan kemajuan elektronik kuasa menukar peranti dan teknologi digital, perkembangan kaedah anggaran kelajuan telah dilaksanakan dengan intensif daripada ramai penyelidik. Oleh itu, bidang penyelidikan ini telah menjadi lebih berminat untuk menyiasat. Teknik sensor-kurang kawalan kelajuan boleh membuat mudah perkakasan dan meningkatkan kebolehpercayaan motor tanpa sensor maklum balas memperkenalkan dan ia menjadi lebih penting dalam pemacu servo moden yang AC. Ia merupakan salah satu arah penyelidikan yang menarik dalam bidang kawalan servo kepersisian tinggi kerana ciri-ciri yang teguh, kesedaran mudah dan gerak balas dinamik yang sangat baik. Beberapa kelajuan biasa anggaran pemutar telah diperkenalkan dalam tesis. Model harus secara tepat mewakili kedua-dua interaksi elektrik dan elektromagnet dalam mesin dan sistem mekanikal yang berkaitan. Tesis ini, pengawal rangkaian neural untuk anggaran kelajuan telah dibangunkan pendekatan untuk motor aruhan yang telah dilaksanakan dalam pemrosesan isyarat digit pengawal (DSP) dan memberi isyarat kawalan ke IGBT untuk jangka masa tiga fasa motor induksi. Analisis ciri-ciri tak linear anggaran kelajuan dijalankan dan membuat perbandingan dengan kelajuan tradisional kaedah linear kaedah sensor yang kurang. Pertama, simulasi sistem kawalan yang dicadangkan dijalankan dengan menggunakan perisian MATLAB dan pelaksanaan masa nyata dilakukan dengan menggunakan MATLAB dan perkakasan. Menurut model motor aruhan matematik, simulasi model dan pelaksanaan perkakasan kelajuan sensor-kurang motor aruhan telah berjaya dilaksanakan. Reka bentuk dan pelaksanaan sistem anggaran kelajuan motor aruhan tiga fasa dan penyelidikan eksperimen dibentangkan di dalam tesis ini. Akhirnya, Tesis ini menunjukkan pelaksanaan anggaran kelajuan menggunakan DSP pengawal dan reka bentuk perkakasan dan perisian untuk sensorless kelajuan motor aruhan. Eksperimen itu selesai pada kelajuan yang berbeza dan hasil eksperimen menunjukkan bahawa pengawal rangkaian neural tiruan mendapat sambutan yang baik berbanding dengan kaedah konvensional.

REFERENCES

Bose B.K, 2007. Neural Network Applications in Power Electronics and Motor Drives, An Introduction and Perspective. *Trans. on Industrial Electronic.* **54**.

Bartolini G, Damiano A, Gatto G, Marongiu I, Pisano A, and Usai E, 2003. Robust speed and torque estimation in electrical drives by second order sliding modes. *IEEE Trans. Control Syst. Technol.* **11**: 84-90.

Bolognani S, Tubiana L, and Zigliotto M, 2003. Extended kalman filter tuning in sensorless pmsm drives,. *IEEE Transactions on Industry Applications.* **39**: 1741-1747.

Bonkas T.K, Habetler T.K, 2004. High-performance induction motor speed control using exact feedback linearization with state and state derivatice feedback. *IEEE Trans. on Power Electronics.* **19**: 1022-1028.

Briz F, Diez A, and Degner M.W 2002. Dynamic operation of carrier signal injection based sensorless directed field oriented AC drives. *IEEE trans Electron.* **65**: 13601368.

Buja, G. S, Kazmierkowski, M.P., 2004. Direct torque control of PWM inverter-fed AC motors *IEEE trans Electron.* **51**: 744-757.

Escobar G, Stankovic A.M, Galvan E, Carrasco J.M, 2003. A family of switching control strategies for the reduction of torque ripple in DTC,. *IEEE Trans. on Control Systems Technology* **11**(6): 933-940.

Fitzgerald. A, Umans S.D, 2006. Quadratized Three-Phase Induction Motor Model for Steady-State and Dynamic Analysis. *Electric Machinery, 6th.* **72**: 79-89.

Holtz, J.2006. Sensorless Control of Induction Machines – With or Without Signal Injection. *IEE Elect. Power Applicat.* **53**: 7-30.

Ilas C, Ferraris L, Griva G and Prohmo F, 2005. Comparison of different schemes without shaft encoders for field oriented control drives. IECON 2005. Bologna Itali.

Kubota H and Matsuse K, 2005. Speed sensorless field oriented control of induction machines using flux observers. !ECON 2005. Bologna, Italy.

Kim Y.R, Sul S.K and Park M.H, 2007. Speed sensorless vector control of induction motor using extended Kalman filter. *IEEE trans industry Application.* **30**: 1225-1233.

Lascu C, Boldea I, Blaabjerg F, 2005. Very-low-speed variable-structure control of sensorless induction machine drives without signal injection. *IEEE Trans. Ind. Appl.* **41**(2): 591-599.

Lai Y.S and Chen J.H ,2001. A new approach direct torque control of induction motor drives for constant inverter switching frequency and torque ripple reduction. *IEEE Trans. Energy Conversion*,. **16**(3): 220-227.

Lee K.B, Blaabjerg F, 2005. Disturbance observer that uses the radial basis function networks for low speed control of electric machine. *Inst. Elect. Eng., Contr. Theory Appl.* **152**: 118-125.

Lee K.B, Choy I, and Yoo J.H, 2001. Improvement of lowspeed operation performances of DTC for 3-level inverter-fed induction motors,. *IEEE Trans. Ind. Electron.* **48**: 1006-1014.

Leksono Edi, 2000. Fuzzy Auto Reset Controller For Speed Sensorless Induction Motor Drive. IECON 00. Nagoya, Japan.

Lin F, Wan C.Y, 1999. Sliding mode and fuzzy control of toggle mechanism using PM synchronous servomotor drive. *IEE Elect. Power Applicat.* **144**: 393-402.

Mohamadian M.N, Ashrafzadeh F, 2003. A novel neural network controller and its efficient DSPimplementation for Vector-controlled induction motor drives. *IEEE TraNs. iND. Applicat.* **39**: 1622-1629.

Ouhrouche M. A, 2002. Estimation of Speed, Rotor Flux and Rotor Resistance in Cage Induction Motor using EKF algorithm,. *International Journal of Power and Energy Systems.* **22**: 1201-1211.

Panigrahi B.P, 2007. A simple hardware realization of switching table based direct torque control of induction motor. *Elsevier.* **77**: 181-190.

Panigrahi B.P, 2005. Digital Simulation and PC based implementation of switching table based Direct Torque Control of induction motor drive. IIT conference. kharagpur.

Pisano. A.D, Fridman.L, and Usai.E.2008. Cascade control of PM DC drives via second-order sliding-mode technique. *IEEE Transactions on Industrial Electronics*,. **55**: 3846-3854,.

Qiang Lu, Xiao-long Ji, and Meng Yong-qing, and Proceedings of the CSEE, vol.26, pp.164-168 2006. A novel sliding-mode observer for speed-sensorless induction motors. *Elsevier.* **26**(CSEE): 164-168.

Qinghui Wu, et al.2009. Research on neural network inverse model of induction motor drives. *IEEE JOURNAL.* **9**.

Song J.L, Song J.H, Choy I, Kim K, 2000 IEEE Industry Applications Society Conference, vol. 3, pp. 1828-1834, Sensorless vector control of induction motor using a novel reduced-order extended Luenberger observer. *IEEE Industry Applications Society Conference*,. **3**: 1828-1834.

Trzynadlowski A.N, 2005. The field orientation principle in control of induction motors. *MA Kluwer Academic*. **7**: 201-206.

Wan Jun,Wan Min, and Ma Yan-bing, Proceedings of the CSEE, 2005.2005. Speed sensorless drive of induction machine using fundamental frequency current injection. *Elsevier*. **25**(CSEE): 163-167.

Xu Z and Rahma M.F, 2007. Direct torque and flux regulation of an ipm synchronous motor drive using variable structure control approach. *IEEE Transactions on Power Electronics*. **22**: 1198-1214.

Xianzhong Dai, Guohai L, 2006. Neural network inverse synchronous control of two-motor variable frequency speedregulatingssystem. ICNSC 06. BEIJING, CHINA.

Xianzhong, W. X, 2007. The ANN inverse control of induction motor with robust flux observer based on ESO. *IEEE JOURNAL*. **7**: 196-205.

Zhao Dezong, and Hao Lan-ying, 2007. A robust sliding-mode control strategy of a speed sensorless induction machine *Elsevier*. **26**: 122-127.

Zulkarnain Lubis, Ahmed. N. Abdalla, Mortaza bin Mohamed, Ruzlaini Ghoni, SollyAryza, 2010. A Novel Nonlinear Torque And Current Control of the Induction Motor Couple DC Motor MUCET 10. Pahang, Malaysia.